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SIMPLE EXPERIMENTS IN PHYSICS IN PROPERTIES OF MATTER

JOHN F. WOODHULL

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SIMPLE EXPERIMENTS

IN

PHYSICS

MECHANICS, HEAT, FLUIDS

BY

JOHN F. WOODHULL, PH. D.

Professor of Physical Science, Teachers College
Columbia University, New York City

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Simple Experiments in Physics.

MECHANICS.

MATTER.

The Extreme Divisibility of Matter. The Molecule. Physical and Chemical Changes.

EXPERIMENT 1.—Dissolve a pinch of common salt in a test-tube one-third full of water. The solution tastes salty and will continue to taste so even if very much diluted.

In another test-tube make a solution of silver nitrate by dissolving a crystal of silver nitrate in a test-tube one-third full of water. To a little of the salt solution add a drop or two of the silver nitrate solution. A white precipitate of silver chloride will be produced. Take some more of the salt solution and dilute it very much. Add silver nitrate. This silver nitrate may evidently be used as a test for salt in solution. Dilute the salt solution so much that you have only a drop or two of it to a test-tube full of water. Add silver nitrate. The white silver chloride still appears.

The reaction for silver nitrate on common salt (sodium chloride) is as follows:

Silver nitrate+Sodium chloride=Silver chloride+ Sodium nitrate. The sodium nitrate remains in solution, but the insoluble silver chloride appears as a precipitate.

EXPERIMENT 2.—Dissolve a crystal of copper sulphate about the size of a pea in a test-tube one-third full of water. Notice that the solution has a distinct blue color like the crystal.

Take out a little of the solution into another test-tube and add to it a drop or two of ammonia water. Notice the very deep blue color. This color appears when ammonia is added to a solution containing any copper salt. It may therefore be used as a test for the copper sulphate in solution.

Dilute some of the copper sulphate very much so that it has lost its characteristic color. Prove that traces of it are still present in solution by adding the ammonia and noting the blue color. Now almost fill the test-tube with water and add a very few drops of the copper sulphate solution. Shake. Add ammonia. The ammonia still detects the presence of the copper sulphate.

EXPERIMENT 3.—One small grain of potassium permanganate will very perceptibly color a large volume of water. Try it. The aniline dyes may be used instead of potassium permanganate.

EXPERIMENT 4.—A very small piece of camphor or a drop of perfumery, ether or carbon bisulphide will fill a large space with its particles, which are easily detected by the odor.

Experiments 3 and 4 with potassium permanganate, camphor, etc., illustrate *physical changes* because the identity of the substances was not destroyed. The smallest particles thought of in physical changes are molecules.

Experiments 1 and 2, in which salt and silver nitrate or copper sulphate and ammonia were brought together, illustrate *chemical changes* because the substances disappear and new substances are formed in their place.

The two following experiments also illustrate chemical change. The smallest particles thought of in chemical changes are *atoms*.

EXPERIMENT 5.—Heat a little mercuric oxide in a test-tube. Mercuric oxide is a chemical compound containing mercury and oxygen. Heat breaks down this compound into mercury and oxygen. The mercury condenses on the cool sides of the tube forming a mirror. The oxygen gas which is given off may be tested by bringing a glowing piece of charcoal to the tube. For this purpose the end of a splinter of wood may be charred until it will no longer burn with a flame in the air. When the glowing charcoal is brought to the tube containing oxygen it springs into a bright flame. Oxygen makes the charcoal, which will only glow in the air, burn very brilliantly.

EXPERIMENT 6.—Make a thick sugar syrup by boiling sugar and water. When the syrup is cool put it to about the depth of an inch into a small tumbler. Pour upon it sulphuric acid very slowly, stirring all the time with a glass rod. The syrup will turn brown and then black and will gradually become very thick. Finally the thick black mass will overflow the tumbler. (Fig. 1.) Sugar is a compound of carbon, hydrogen and oxygen. The sulphuric acid takes the hydrogen and oxygen from the sugar, setting free the carbon.

Fig. 1.

STATES OF MATTER.

EXPERIMENT 7.—Examine a piece of sulphur (roll brimstone). It is a yellow solid. It has neither odor nor taste. Heat a small piece gently in a shallow dish. It first melts and then begins to burn with a pale blue flame. Note the odor of the burning sulphur. The sulphur in burning unites with the oxygen of the air, producing sulphur dioxide gas. The element sulphur has no odor but the compound sulphur dioxide has a very distinct and characteristic odor. The sulphur has undergone a chemical change.

This same sulphur dioxide gas may be made by burning sulphur in the air. It may be made by the action of concentrated sulphuric acid on copper.

EXPERIMENT 8.—Put a small piece of copper wire into a test-tube. Cover it with concentrated sulphuric acid. Heat gently, shaking the tube to keep it moist with the acid. Note the odor of the gas produced. This is the same gas that is produced when sulphur burns in the air or in oxygen.

The sulphur dioxide, which is a gas at ordinary temperatures, may be changed into a liquid quite readily. Most gases may be liquefied if they are subjected to a sufficiently low temperature and high pressure. Sulphur dioxide gas may be liquefied at the ordinary pressure and at a temperature of about 14° F. (—10° C.)

EXPERIMENT 9.—Into the flask, figure 2*, put several pieces of copper wire. Add enough concentrated sulphuric acid to cover the copper. Heat the contents of the flask gently, shaking the flask all the while to keep

*The construction of apparatus mentioned in this book is fully described in Vol. 1, Home-Made Apparatus, of this series.

it well moistened by the acid. It is apt to break if allowed to become dry in one place. When there is evidence that the sulphuric acid has begun to work on the copper it will not be necessary to heat the flask longer. Now allow the delivery tube from the flask to pass over into the test-tube surrounded by a freezing mixture of ice and salt or snow and salt well packed around the tube. Allow the action to continue for some time. At the end of about 15 minutes it should be found that about a thimbleful of liquid sulphur dioxide has been collected in the test-tube. It will be observed that the liquid evaporates very rapidly. Pour it into a thimbleful of water in a test-tube. Note the very rapid evaporation. The evaporation is so rapid and requires so much heat that the water in the test-tube is frozen. This strange phenomenon will be treated later.

Fig. 2.

Heat changes solids to liquids and liquids to gases. All matter is composed of small particles with spaces between them. The intermolecular spaces are larger than the molecules themselves. This is the molecular theory of the constitution of matter. Heat acts like a force within a mass to drive these particles further apart. Heat overcomes the force of cohesion between the particles, so heat changes the solids to liquids and the liquids to gases. The more solid the matter, the greater is the cohesion between its particles.

Some substances pass from the solid to the liquid and even to the gaseous state at ordinary temperatures.

EXPERIMENT 10.—Put a few crystals of solid iodine into a flask. Heat very gently. The iodine passes into a beautiful purple vapor.

It would appear that the iodine had passed from the solid state directly to the gaseous without passing through the liquid state. This is possible, for we know that solid camphor gum vaporizes and clothes "freeze dry."

EXPERIMENT 11.—Put a small piece of ice in a test-tube. Heat gently. The ice passes into the liquid state. Heat the water formed to the boiling point, and hold at the mouth of the tube a cold tumbler. Drops of water collect on the tumbler. The water passed from the test-tube in an invisible state—water vapor—and condensed on the cool tumbler. This was the process of distillation. This process is illustrated by what goes on in the laundry. The water evaporates from the boiler and is condensed to drops on the cold window pane.

Fog; mist; clouds; rain: dew.

EXPERIMENT 12.—Use a distilling apparatus, figure 3, and into the flask put some salt water. Boil this water. The water vapor will pass over through the delivery tube in an invisible state, and will condense in the test-tube, which is kept cool by being surrounded with water The salt will be left in the flask. Taste the distilled water.

Fig. 3.

INDESTRUCTIBILITY.

Preliminary. Dissolve some copper sulphate in water, in a test-tube. Dilute the solution very much, so

that it has lost its characteristic color. Now add a few drops of ammonia. Notice that the solution turns bright blue. This color test is always obtained when ammonia is added to a solution of a copper salt.

Dissolve some copper nitrate in water in a test-tube. Then proceed as in the former experiment.

EXPERIMENT 13.—Dissolve a piece of copper wire in dilute nitric acid, in a test-tube. You now have a solution of copper nitrate. Into this solution dip a knitting needle. Notice that the knitting needle becomes coated with a deposit of copper. This copper must have come from the copper nitrate solution.

EXPERIMENT 14.—Dissolve some copper sulphate in water in a test-tube. Dip a strip of zinc into the solution. Notice the deposit that collects on the zinc. After the zinc has become well coated, dip it into nitric acid. The deposit dissolves in nitric acid. When it is all dissolved away from the zinc, add to the solution a few drops of ammonia. The blue color indicates that there was a copper salt present.

When we put the zinc into the copper sulphate solution the zinc changed places with the copper, that is, instead of copper sulphate and zinc we were getting zinc sulphate and copper. The copper dissolved in nitric acid, forming copper nitrate. The presence of the copper nitrate was recognized by the ammonia test.

INERTIA.

EXPERIMENT 15.—Tie a stout cord around a rather heavy book and suspend it. Fasten also a weak thread to the book and attempt to jerk it sideways. The thread breaks and the book is loth to move. Swing the book violently and attempt to stop its motion by a sudden jerk of the thread. The thread breaks

and apparently does nothing toward stopping the motion of the book. *A body at rest tends to remain at rest and a body in motion tends to continue moving. Both of these tendencies are called inertia.*

EXPERIMENT 16.—Lay a sheet of writing paper upon the table and place a book upon it. Snatch the paper from underneath the book without moving the book at all.

EXPERIMENT 17.—Lay a small card upon the top of a wide-mouthed bottle and place a coin upon the card. Try snapping the card half way across the room and have the coin at the same time fall into the bottle. If you are unable to do this tie a string to the card and jerk it out from under the coin.

EXPERIMENT 18.—Suspend a heavy book by a string (thread) from a support. Attach also a thread of the same kind to the under side of the book. First pull slowly and steadily on the lower thread. The upper thread will probably break because it has the weight of the book to support while it is resisting the pull on the lower thread. Now pull very quickly and suddenly on the lower thread. The lower thread itself will probably break this time. The book is quite as loth to move from its state of rest downward as it was to move horizontally, in experiment 15.

Why is a person leaping to the ground from a rapidly moving carriage likely to fall in the direction in which the carriage is going?

In getting on and off a moving car in which direction should one face? Why?

Why is a rider thrown forward when his horse suddenly stops?

IMPENETRABILITY.

EXPERIMENT 19.—Use an eight-ounce wide-mouthed bottle, figure 4, carrying a rubber stopper (No. 7) with two holes. Through one hole of the stopper insert the stem of a small funnel. Through the other hole insert a piece of glass tubing bent into a right angle. Attach to the latter a piece of rubber tubing which may dip into a tumbler containing some water.

It is usual to speak of the bottle as empty, but it is filled with air which occupies the space to the exclusion of other things. To illustrate this, pinch the rubber tube and pour water into the funnel. The water does not run down into the bottle but remains in the funnel. Release the rubber tube, the water immediately runs into the bottle of air and the air passes out through the rubber tube and bubbles through the water in the tumbler. Repeat the experiment several times, pinching the tube and pouring water into the funnel and then releasing it and allowing the water to displace or take the place of the air.

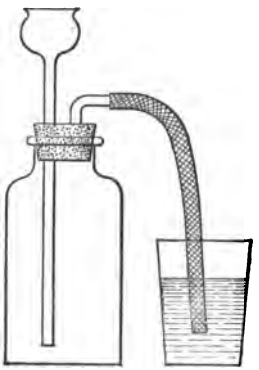

Fig. 4

By impenetrability is meant that property by virtue of which two bodies cannot occupy the same space at the same time. If a stone be lowered into a vessel filled with water, the vessel will overflow. It will overflow by an amount equal to the volume of the stone. Advantage is taken of this displacement in finding the volume

of irregular bodies, the volume of which cannot be easily computed.

POROSITY.

EXPERIMENT 20.—Sink a piece of charcoal, a piece of crayon, or a piece of wood in water. They all soak up a greater or less volume of water. While they are soaking up the water, considerable air is seen to escape through the pores of these bodies. They all soak up enough water to become water-logged in time and will then lie upon the bottom without being weighted. These substances are all porous. We have many reasons for believing that all matter is composed of small particles with spaces between them, and even when these spaces are not at all evident we have reason to believe that they exist, for every body may be diminished in volume or crowded into a smaller space, and the following experiment will illustrate that when two liquids like water and alcohol are intimately mixed a shrinkage in volume occurs:

EXPERIMENT 21.—Use a small test-tube of such size that the mouth may be closed by your thumb. Fill the tube about half full of water. Tilt the tube and pour in alcohol carefully so that it will float on the water and not mix with it. Hold the thumb over the open end of the tube and mark the level of the alcohol with a rubber band. Now invert the tube several times so as to allow the water and alcohol to mix. Notice that the volume is perceptibly smaller than at the beginning. The water has penetrated the spaces between the particles of alcohol. Notice that bubbles of air are evidently being expelled.

EXPERIMENT 22.—A device used for cleaning mercury illustrates very strikingly the porosity of a piece of chamois skin.

Use an eight ounce bottle fitted with a rubber stopper with two holes. Through one hole run the stem of a small funnel and through the other a glass tube bent in a right angle. To this may be attached a piece of pressure tubing connected with the exhaust valve of an air pump. Line the funnel with a piece of chamois skin and into this pour the dirty mercury. Now exhaust air from the bottle. A shower of mercury particles will fall through the chamois skin into the bottle.

COMPRESSIBILITY AND ELASTICITY.

EXPERIMENT 23.—Air and all gases are perfectly elastic. However great the pressure applied, they recover their original volume as soon as the pressure is relieved.

Because of the elasticity of air we may cause a fountain to play by compressing the air in a bottle. For this purpose use a 12 or 16 oz. narrow-necked bottle. Fig. 5. The bottle should be fitted with a rubber stopper containing one hole. Through the hole insert a glass tube nearly closed at one end, that is, considerably constricted so as to throw a jet. Allow the constricted end to project about two inches outside the neck of the bottle. Allow the other end to just dip into water in the bottle. The bottle may be about one-third full of water. Put a piece of rubber tubing about 4 inches long on the constricted end. Blow air through this tube from the lungs into the bottle. It will bubble through the water into which the glass tube dips and will compress the air in the bottle. Pinch the rubber tube while you take another breath and then blow again. Now pinch and quickly remove the rubber tube from the glass tube. A fountain

Fig. 5.

will play through the jet into the air. The pressure of the atmosphere on the jet is about 15 lbs. per square inch, or 1033 gms. per sq. cm. The pressure inside of the bottle was made more than 15 lbs. by compressing the air. Therefore, the air in the bottle presses on the water in the bottle and drives it up through the glass tube. When the air in the bottle has regained its original tension, that is, when it is at the same tension as the atmosphere which is pressing on the jet, the fountain will cease to play.

EXPERIMENT 24.—To study the elasticity of rubber, a piece of rubber band or rubber elastic may be first measured and then stretched and measured again. It will be found that within certain limits it is perfectly elastic, but if stretched beyond a certain point it will not recover and it will be definitely and permanently lengthened.

EXPERIMENT 25.—Draw a piece of glass rod or tubing out into fine threads. Bend these and notice how elastic they are. They may be bent very much without breaking.

The efficiency of a spring balance depends on the elasticity of the steel spring.

There is a "limit of elasticity" for most substances within which they are perfectly elastic. Beyond this they either break or do not entirely regain their original form.

HARDNESS, BRITTLENESS, DUCTILITY, MALLEABILITY, AND TENACITY.

All these properties of matter may be illustrated by glass.

EXPERIMENT 26.—*Hardness:* The relative hardness of two bodies is ascertained by finding which

of them will scratch the other. Try scratching glass with copper and copper with glass. Which is the harder? Diamond scratches all bodies, but is not scratched by any; therefore, it is the hardest of all substances.

EXPERIMENT 27.—*Brittleness:* Scratch a piece of glass tubing with a triangular file. Break the tubing by holding the fingers opposite to the scratch. The cold glass tubing is very brittle.

EXPERIMENT 28.—*Ductility:* Hold a piece of glass tubing in the hottest part of a Bunsen burner flame. Twirl the tubing so that it becomes well heated on all sides. When it becomes so soft that it is difficult to twirl it longer remove it from the flame and pull it out into a fine thread. Capillary tubes are made in this way to illustrate capillarity. Prove that this thread of glass is a tube by breaking off a piece of it and blowing through it or putting it into water. "Dropper" tubes or "medicine droppers" are made in this way.

EXPERIMENT 29.—*Malleability:* Heat the end of a piece of glass rod or tubing very hot. Flatten it out by pressing it between forceps.

Steel may be rolled into sheets as thin as paper.

The most malleable of metals is gold. It may be beaten into sheets one three-hundred-thousandth of an inch in thickness.

Tenacity. A sheet of writing paper is easily torn but it is difficult to tear it by a pull in the direction of its length. It will be found that a surprising effort is required to break the paper. We say its tenacity or its breaking strength is great. By breaking strength we mean the force required to pull it apart. A piece of brass wire 14-thousandths of an inch in diameter was

found to sustain about 20 lbs. or 9 kilograms pull before breaking. The breaking strength of the wire was then said to be about 20 lbs. Ordinarily the breaking strength of bodies is found by forming them into cylinders as in the case of the brass wire and finding what force will be required to break them. The breaking strength of various threads and silks could be found as follows:

EXPERIMENT 30.—Wind one end of the thread to be tested (a piece of linen thread will give satisfactory results) around some convenient support—a nail for instance—and then attach the other end of it to the hook of a spring balance. Pull slowly and steadily and note the balance reading when the thread breaks. Compare the breaking strength of several threads of silk, linen, and cotton. Compare the breaking strength of these several threads without the spring balance by holding an end in each hand and pulling steadily in the direction of the length of the thread.

ADHESION, COHESION, AND CAPILLARITY.

EXPERIMENT 31.—Touch the end of your finger to the surface of water and lift it slowly. Particles of water cling together in a drop and hang upon the finger tip. The clinging of water to the finger is called adhesion and the clinging of the particles of water together to form a drop is called cohesion.

Repeat the experiment substituting for the finger a glass rod; a zinc rod; a wax taper.

Repeat also the experiment substituting mercury for water in each case. If the zinc rod is thoroughly cleaned by sandpaper or by filing the end of it, the mercury will adhere to it and be absorbed by it.

EXPERIMENT 32.—Draw out capillary tubes of glass and thrust them into water. Thrust them into mer-

cury. Try tubes of different sizes. Notice that the water rises higher in the smaller tubes. Touch the end of a blackboard crayon to some ink and hold it there until the ink rises up in the crayon by capillary attraction. Sponge, candle, lamp wicks, etc.

CRYSTALLIZATION.

On examining different crystals such as alum, copper sulphate, potassium bichromate, sugar, common salt, rock candy, etc., it is found that they all have characteristic shapes and colors.

EXPERIMENT 33.—Make alum crystals by suspending a string for several days in a beaker containing a saturated solution of alum. The saturated solution is made by dissolving all the alum that will dissolve in about a pint of water. The water is heated to the boiling point while the alum is dissolving.

Make a basket of alum crystals by suspending in the alum solution a basket woven from fine copper wire covered with an insulation of cotton.

EXPERIMENT 34.—Make copper sulphate crystals and a copper sulphate basket in the same way as above.

In the same way make a basket of potassium bichromate crystals.

EXPERIMENT 35.—Fill a test-tube about half full of ammonium chloride and add water so that the test-tube is about two-thirds full. Shake the test tube so as to dissolve as much of the ammonium chloride as possible. Then heat the tube until all the ammonium chloride is dissolved. Allow the solution to cool slowly and watch the crystals form.

Do the above experiment on a larger scale by dissolving 100 grams of ammonium chloride in 200 grams of water. Keep this in an 8-ounce flask and preserve it as

a permanent piece of apparatus, heating it up from time to time as wanted to present the experiment.

EXPERIMENT 36.—Show the expansive force of crystallization by filling a one-ounce, narrow-mouthed bottle with water, corking it and surrounding it with a freezing mixture of ice and salt. After allowing it to stand for fifteen or twenty minutes the bottle will break and the cork will be pushed out an inch or two on a plug of ice. Type metal, etc.

EXPERIMENT 37.—Melt some paraffin in a small jar over boiling water. When the cup is even full of the melted paraffin allow it to cool and notice that on cooling it contracts very perceptibly. This suggests that the structure of these substances (that is wax and paraffin and other substances like them that cannot be cast in molds) is unlike the structure of the substances mentioned above which crystallize on cooling.

VISCOSITY.

Examine a piece of sulphur. At ordinary temperatures it is a yellow, brittle solid. If cooled to—58° F it becomes colorless. When heated it undergoes very interesting physical changes, getting darker and darker until finally, at the boiling point, it is almost black.

EXPERIMENT 38.—Put into a test-tube to the depth of about two inches, small pieces of sulphur of nearly uniform size. Turn the Bunsen burner flame quite low and heat the sulphur gently until it all melts. If this part of the experiment is done carefully you will now have a very pale yellow liquid. Cool the liquid by passing your hand over the test-tube. The middle of the mass will be the last to solidify. When the outside has hardened and the middle is yet liquid, tilt the tube so as to allow the liquid to run out of the middle. This

will enable you to see the crystals which have grown from the sides of the tube toward the middle. They are very beautiful needle-shaped crystals.

Now heat the sulphur gradually to a higher temperature. Notice that it turns darker and passes to an amber-colored stage and then to a dark red. At this point it is much thicker and even if the test-tube is inverted it will not run out. This is the viscous stage. This property of matter is called viscosity. Pitch, tar, balsam and honey exhibit this property in a marked degree. Now heat the sulphur still hotter. It gets darker and darker and finally boils. Below are some of the temperatures through which the sulphur has passed.

When the sulphur boils it may be poured out into a basin of water. Care should be taken to keep the hand in such a position that the hot sulphur shall not come in contact with it. The face should not be held directly over the basin as the sulphur sometimes sputters when it strikes the water.

Sometimes the sulphur springs into a blue flame when it strikes the air. This indicates that the sulphur was heated above its kindling temperature but could not burn inside the tube because of a lack of oxygen.

It will be found that on cooling the sulphur goes back through the various stages through which it passed when you heated it. Finally it becomes again a hard yellow solid. Asphalt, rosin, sealing wax, glaciers, etc.

TEMPERATURES FOR THE VARIOUS STATES OF SULPHUR.

Colorless solid, below—58° F. (—50° C.)
Yellow brittle solid, at ordinary temperatures.
Thin straw-colored liquid, 238° F. (114° C.)
Viscous, cherry colored, about 400° F. (204° C.)

Boiling point. Gives off yellow vapor, about 839° F. (448° C.)

The above temperatures are approximate.

OSMOSE.

EXPERIMENT 39.—Put about an inch of concentrated sugar syrup or copper sulphate into a test-tube. Tie gold beater's skin or a piece of bladder over the neck of the tube. Invert the tube over a tumbler containing water and crack a hole in the bottom of the test-tube. Allow the apparatus to stand several days. At the end of this time it will be found that the sugar syrup (or copper sulphate) has passed into the water and water has passed into the sugar syrup (or copper sulphate). This tendency of liquids to diffuse through porous partitions is called Osmose.

The osmose experiments may be carried on on a much larger scale by using an Argand lamp chimney instead of the test-tube.

Explain the behavior of dried fruits, seeds, etc. in water.

DIFFUSION.

EXPERIMENT 40.—Collect a bottle of oxygen by displacement of water. The oxygen may be made by heating a mixture of potassium chlorate and manganese dioxide. (See vol. 2.) Lower a candle into the oxygen. Notice that the candle burns brilliantly.

Collect a bottle of hydrogen by the action of zinc and dilute (1:8) sulphuric acid. (See vol. 2.) Bring a lighted taper to the bottle of hydrogen. The hydrogen burns at the mouth of the bottle. A mixture of the two gases, one of which burns and the other of which makes things burn, would cause an explosion or combustion throughout the whole mass at one time.

Invert a bottle of hydrogen over a bottle of oxygen. The hydrogen is only one-sixteenth as heavy as the oxygen. Even when the lighter gas is placed on top of the heavier gas, diffusion will take place from one into the other. After they have stood several minutes bring a lighted taper to the mouth of each bottle. Have the gases become mixed?

This property that gases manifest of diffusing into each other accounts for the fact that two gases of different densities, like oxygen and nitrogen, which occur in the atmosphere, are not found in layers but intimately mixed. If it were not for this the lighter nitrogen would be found on top of the heavier oxygen.

This property of diffusion is not confined to gases. We have already noticed that liquids will diffuse through a membrane.—Osmose.

GRAVITY.—CENTER OF MASS.—LINE OF DIRECTION.

Balance a piece of board of uniform cross-section on a lead pencil. When the board is balanced there is an equal weight on either side of the pencil. Balance an irregular-shaped object on a pencil or dowel rod. When the object is balanced the weight must be the same on both sides of the pencil. By balancing the object we may determine the center of the weight of it, and this center of weight is called the center of gravity or the center of mass. In many cases the center of gravity of a body may be at once easily determined. The center of gravity of a sphere, for instance, is its geometrical center.

To find the center of gravity by experiment:

EXPERIMENT 41.—Make several holes around the edge of a large, thick, irregularly-shaped cardboard.

Hang the cardboard by one of these holes on a nail. Make a plumb line by attaching a lead bullet or sinker to a piece of fish line. Suspend this by an ample loop from the same nail as the cardboard and leave it free to swing clear of the cardboard. Wait until both cardboard and plumb line come to rest and then, with a pencil, trace the direction of the plumb line on the cardboard. This line is called a line of direction and it passes through the center of gravity of the body. But the center of gravity cannot be found without tracing another line of direction, and finding the point where these lines cross. This may be done by hanging up the cardboard by any one of the other holes and marking the line of direction as indicated by the plumb line. The center of gravity is, of course, not on the surface where the lines cross, but is midway between the two faces of the cardboard. Try to balance the cardboard on a pin point at the center of gravity.

It is customary to distinguish between three states of equilibrium: stable, unstable, neutral. A cone placed on its base is said to be in stable equilibrium because it would tend to return to its original position if its equilibrium were only slightly disturbed. A body is in stable equilibrium when the slightest alteration in its position elevates its center of gravity. A cone standing on its point is in unstable equilibrium. Any variation in its position makes it tend to depart still more from its original position. Its center of gravity is now in such a position that to tilt the body would cause the center of gravity to be lowered. A cone on its side is in neutral equilibrium. In this position it can be tilted in all directions without raising or lowering its center of gravity.

In what state of equilibrium is an egg on end?

In what state of equilibrium is a stick balanced on the finger?

THE PENDULUM.

Is the time of vibration of a pendulum dependent on the arc through which it swings?

Is the time of vibration dependent on the weight of the bob?

Is the time of vibration dependent on the length of the pendulum?

Just how is the time of vibration dependent on the length of the pendulum?

Which takes longer to swing, a long or a short pendulum?

Which makes more swings in a given time, a long or a short pendulum?

(In measuring the length of your pendulum always measure from the middle of the bob.)

EXPERIMENT 42.—Use first a pendulum with a 2 in. ball for a bob. Make the pendulum 18 in. long. Swing this for 30 seconds through a small arc and record the number of swings. Now swing it for 30 seconds through a larger arc and record the number of vibrations. Is the time of vibration dependent on the length of the arc?

EXPERIMENT 43.—Now use a pendulum 18 in. long but substitute a 1 in. bob for the 2 in. bob. How many times as heavy is the 2 in. bob as the 1 in. bob? How do the number of vibrations made by the pendulum with the 1 in. bob compare with the number made by the pendulum with the 2 in. bob? Is the time of vibration dependent on the weight of the bob?

EXPERIMENT 44.—Now swing successively a 9 in., 36 in., and an 81 in. pendulum. Count the number of

vibrations made in each case in 30 seconds. On what does the time of vibration depend?

How many times as many vibrations did the 9 in. pendulum make as the 36 in. pendulum? Did it make about twice as many? How many times as many did the 9 in. one make as the 81 in. one? Did it make about three times as many?

How long did it take the 9 in. one to swing as compared with the time it took the 36 in. one to swing? One half as long. How long did it take the 9 in. one to swing as compared with the time it took the 81 in. one to swing? One third as long. Do you discover any relation between their relative lengths and the time it takes them to swing? The time varies as the square root of the length.

LAWS OF THE PENDULUM.

The time of vibration is not dependent on the length of the arc.

The time of vibration is not dependent on the weight of the bob.

The time of vibration is dependent on the length of the pendulum.

Time of vibration varies directly as the square root of the length.

Number of vibrations vary inversely as the square root of the length.

MACHINES.

EXPERIMENT 45.—Fasten a ruler so that it is free to swing about the middle or Fulcrum. Hang a weight (an ounce or a 25 gram weight) at any distance from the fulcrum on the right hand side. See where an equal weight on the left side will need to be placed to balance the bar. Record several trials, making the

right hand weight twice what it originally was, placing it at different distances from the fulcrum and finding where the left hand weight (still one ounce) will need to be placed in order to balance the bar. Make a table as follows:

Rt. Wt. = ; Rt. Dis. = ; Left Wt. = ; Left Dis. =

It will probably be found that the product of the right hand weight by the right hand distance is about equal to the product of the left hand weight by the left hand distance.

By a lever is meant an inflexible bar movable about a fixed axis called the Fulcrum. The parts of the lever into which the fulcrum divides it are called the Arms. When the arms are in the same straight line the lever is straight, otherwise it is bent. If the fulcrum be between the points of application of the effort and the weight, the lever is of the first class.

The above piece of apparatus illustrates the law for machines. The effort multiplied by the distance through which it acts is equal to the load multiplied by the distance through which it is moved.

Figure 6 represents a strip of wood (*mn*) containing several tacks, to which spring balances may be attached by means of threads. The apparatus is used horizontally upon a table. In exercises with this apparatus certain of the forces are given in each case. It is required to determine the remainder. It should be first calculated according to the principles and the result afterwards verified by using the apparatus represented in figure 6.

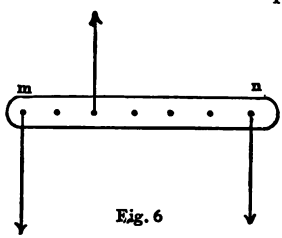

Fig. 6

(1) Why are long-handled shears used in cutting metal?

(2) A druggist has a balance, the arms of which are in the ratio of 4 to 5. He sells 5 ounces of a drug to one man weighing it on the right pan of the balance. To another man he sells 5 ounces weighing it on the left pan. Show that by the two transactions he lost one-fourth ounce.

The general law of machines adapted to the lever is: The weight multiplied by the distance through which it acts equals the effort multiplied by the distance through which it is applied.

Or, a given power will support a weight as many times as great as itself as the power arm is times as long as the weight arm.

There are three classes of levers, depending upon the relative positions of power, weight, and fulcrum.

FIRST CLASS: Fulcrum between power and weight.

SECOND CLASS: Weight between power and fulcrum.

THIRD CLASS: Power between weight and fulcrum.

EXPERIMENT 46.—To illustrate levers of the second and third class:

Suspend a load at a point 2 in. from the middle of the lever and on the same arm of the lever, at a distance of 4 in. from the middle, pull upward with a spring balance connected with the lever by means of a loop of thread, until the weight is balanced and the lever becomes horizontal. You have here a lever of the second class. Read the spring balance and record. Make several trials in order to accumulate data.

The nut cracker is an interesting illustration of a lever of the second class.

Using the same apparatus, place the spring balance between the fulcrum and the weight. You will now have a lever of the third class. Try various cases.

Illustrations: Candy or sugar tongs; fire tongs; lifting a weight from the table by bending the elbow.

WHEEL AND AXLE.

EXPERIMENT 47.—From stout cardboard cut a circle about 13 inches in diameter, figure 7. Fasten it to the moulding above the blackboard by a wire nail at the center *c*. Through a hole *b* 1½ inches from the center, pass a string, knot it behind, and hang four spools on the lower end. In a similar manner hang a spool from a point *a* at a distance of six inches from the center. Compare the principle of this model of a wheel and axle with that of a lever.

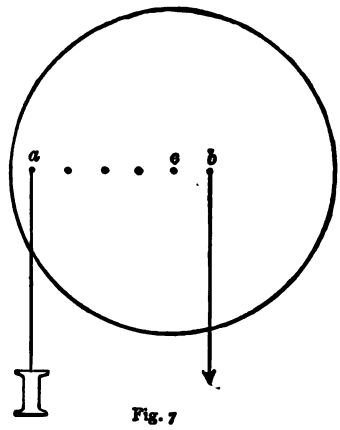

Fig. 7

EXPERIMENT 48.—Make two cardboard circles as in experiment 47. Attach one spool at *a* and find how many spools are needed at *f* to maintain the balance. Figure 8.

In each case measure upon the blackboard the vertical distance through which each set of spools moves. Compare relative weight of each set of spools with distance through which they move and also with lever arms upon which they act.

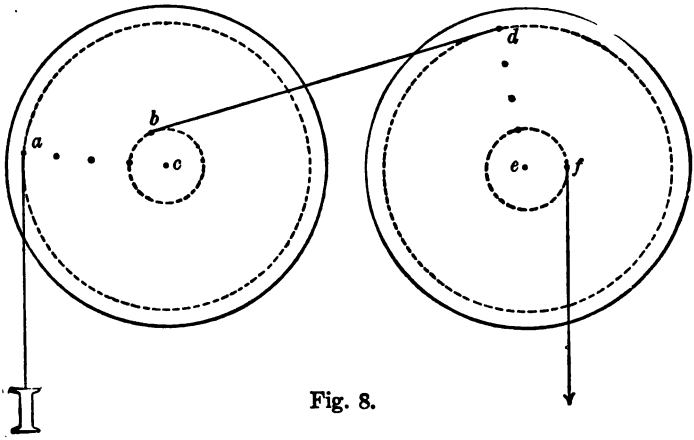

Fig. 8.

INCLINED PLANE.

EXPERIMENT 49.—Fill an ordinary crayon box with shot or nails until it weighs twelve pounds. Rest it upon two pencils or short dowel rods laid upon a smooth board exactly 24 inches long. Connect the box with a spring balance as shown in figure 9. Tilt the board so that the vertical height *bc* shall be four inches, or one-sixth the length *ab* of the board and the spring balance will indicate two lbs. or one-sixth the weight of the box. Make the vertical height *bc* six inches or one-quarter of *ab* and the spring balance will indicate one-quarter of the weight

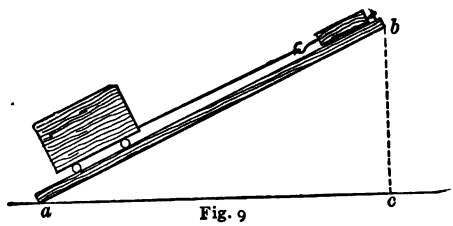

Fig. 9

of the box or three lbs. Make *bc* one-third of *ab* and the spring balance will indicate one-third the weight of the box and so on until when *bc* is equal to *ab* or the board is in a vertical position the spring balance will indicate the full weight of the box, 12 lbs.

The series of observations might be as follows:

24 : 4 : : 12 : 2
24 : 6 : : 12 : 3
24 : 8 : : 12 : 4
24 : 12 : : 12 : 6
24 : 16 : : 12 : 8
24 : 18 : : 12 : 9
24 : 20 : : 12 : 10
24 : 24 : : 12 : 12

Where the first figure in each proportion is the length of the board, the second figure is the height to which the end *b* is elevated above the table top, the third figure is the weight of the box, and the fourth figure is the portion of that weight which exerts a pull upon the spring balances. A general expression of the result might be: $ab : bc : : w : p$.

The ratio of *ab* to *bc* is the common expression of the grade of an incline, as for example: A sewer may have a fall of two inches in a hundred, or two per cent; a railroad may have a grade of 53 feet to the mile or about five per cent.

The above formula indicates that in case a railroad has a grade of five per cent the load of the train is increased by five per cent.

MECHANICS OF LIQUIDS.

THE PRESSURE GAUGE.

To determine by means of the pressure gauge the relative weight of water and mercury:

EXPERIMENT 50.—Put mercury into a J-shaped tube open at both ends, figure 10. The mercury stands at the same height in both arms. Now slowly add water to the long arm, being careful to exclude all air bubbles. The weight of the water presses the mercury up in the short arm. Add a column of water 13 or 14 inches long. Now carefully measure the water column. Then measure the height of the mercury column which the water supports. Divide the height of the water column by the height of the mercury column. This quotient will tell how many times as heavy as water mercury is. This, then, is one way of finding the specific gravity of mercury in terms of water or of water in terms of mercury. The standard result for the specific gravity of mercury in in terms of water is about 13.6.

FIG. 10

One cubic inch of mercury weighs about one-half pound; how much does one cubic inch of water weigh?

If the tube were 1 sq. in. in cross-section and we could by any pressure on one side hold up a column of mercury 1 in. high on the other side we would be supporting 1 cu. in. of mercury, which weighs one-half pound. We would, therefore, be exerting a pressure of one-half pound. But in a tube of any cross-section whatever, we say that when a column of mercury is held up 1 in. high, it is being supported by a pressure which is at the rate of one-half pound per square inch. If the tube

were exactly a square inch in cross-section, the pressure would be exactly one-half pound. If the cross-section is less than a square inch the actual pressure is less than one-half pound, but is at the rate of one-half pound per square inch.

It takes a column of water 13.6 inches long to exert a pressure of one-half pound per square inch. Why?

Attach a large pressure gauge to a water faucet. Remember that every inch of mercury supported means a pressure of one-half pound per square inch. Read the height of the mercury column which the water pressure supports. How long a column of water does it take to exert a pressure of one-half pound per square inch? What pressure is the water column exerting? How long, therefore, must the water column be?

EXPERIMENT 51.—Take a pressure gauge containing only mercury. See how high a column of mercury you can lift by forcing a steady breath from the lungs. Pinch the rubber tube attached to one outlet of the gauge while you make your reading. Remembering that every inch of mercury supported means a pressure of one-half pound per square inch, calculate your lung pressure in pounds per square inch. Read the mercury column in centimeters. Remembering that every centimeter of mercury supported means a pressure of 13.6 gms. per sq. cm, calculate your lung pressure in grams per sq. cm.

EXPERIMENT 52.—To show that pressure is proportional to the depth, proceed as follows: To the short end of a J tube containing water attach by means of a rubber tube a funnel or other tube. Lower the funnel gradually into a jar of water. Note that the pressure increases with the depth. The pressure of the water is transmitted

through the air in the funnel and the rubber tube on to the liquid in the J tube. Find out how high the liquid is pressed up when the surface of the water in the funnel is 2 in., 4 in., 6 in., and 8 in. below the surface of the water in the tall jar. Compare these readings.

EXPERIMENT 53.—To show that pressure is dependent on the depth alone and is not affected by the size or shape of the vessel:

Arrange apparatus as shown in figure 11. The long end of one gauge is extended by a long, straight tube. Another is extended by a chimney and still another by a bottle. The height of the water is made the same in all the cases. Read the mercury columns. The mercury column in the short arm of each will read the same if the water in the long arm is the same in each. Notice that the volume of water differs very much in each case.

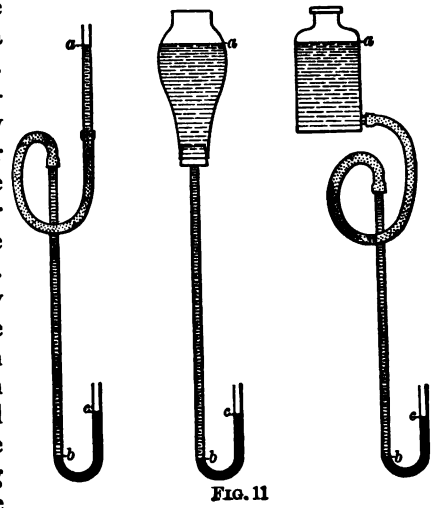

FIG. 11

EXPERIMENT 54.—To further illustrate that pressure increases with the depth:

Attach a funnel to one end of a piece of rubber tubing and to the other end of the rubber tubing a small piece

of glass tubing with one end constricted. Fill the rubber tube with water and partially fill the funnel. Hold the constricted end on a level with the water in the funnel. The pressure is now equal on both arms, that is, the constricted arm and the funnel arm. The water in the constricted arm and the water in the funnel arm are both under the pressure of one atmosphere. Now gradually raise the level of the funnel. The pressure on the constricted end is now being increased by a water column equal to the difference between the lengths of the two water columns. The greater this difference the higher the fountain plays. Lower the funnel arm. When does the fountain cease to play? If the level of the water in the constricted arm is higher than the level of the water in the funnel arm, in which direction is the pressure greater?

EXPERIMENT 55.—To show that at any given depth the pressure is equal in all directions—downward, sidewise, and upward:

Use a bottle carrying a stopper with three holes. Through one hole insert a straight piece of tubing (glass) about 6 in. long as in figure 12. Through another insert a tube containing a right-angle bend. Through the other hole insert a tube bent into a J as in figure. Put the stopper lightly into the bottle, which should be about half-full of water, so that the tubes all dip into the water to the same depth—say an inch or two. Notice that the water is pressing downward on the J tube, upward on the straight tube, and sidewise on the right angle bend.

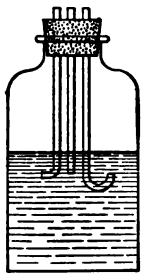

Fig. 12

The water rises to approximately the same height in all three tubes so the pressure on each tube must be the same. Now increase the pressure by crowding the stopper farther into the bottle. Note that the water now rises higher in all the tubes but to the same height in each.

PRESSURE IN LIQUIDS IS:

(1) Dependent on the depth.
(2) Proportional to the depth.
(3) Regardless of size and shape of vessel.
(4) Equal in all directions at any given depth.

BUOYANCY.

EXPERIMENT 56.—Tie rubber cloth over the bottom of a lamp chimney and thrust it down into a vessel of water. Observe and explain the behavior of the rubber cloth. Also note the force necessary to push the chimney down.

According to Archimedes' principle, a body either partially or totally immersed in a fluid loses in weight an amount equal to the weight of the fluid which it displaces. The weight of the fluid displaced is the buoyancy of the fluid on the object. A floating body displaces its own weight of the fluid in which it floats. Therefore the buoyancy on a floating body is equal to its own weight. A body that sinks displaces its own volume of the fluid in which it is immersed. The buoyancy on a totally submerged body is, then, equal to the weight of its own volume of the fluid.

EXPERIMENT 57.—Make an overflow apparatus from a bottle or tin can as follows: Bore a hole with a rat-tail file about an inch from the top. By means of a piece of rubber tubing, fit into the hole, water tight, a piece of glass tubing bent a little as a spout. Fill the

apparatus to the overflow. Weigh in grams a piece of wood. Carefully lower it into the water. Catch the water which is displaced in a measuring glass, and read its volume in cubic centimeters. Assuming the weight of a cubic centimeter of water to be 1 gram, compute the weight of the water displaced. Compare this weight with the weight of the block.

Repeat the experiment, weighing accurately the water displaced. Does the weight of the water displaced equal the weight of the block of wood?

If the adhesion of the water to the glass spout is troublesome, a little oil may be poured through the spout first to prevent the water from clinging to the glass.

The buoyancy of water is due to the weight of water.

A body immersed in water will be buoyed up with a greater force than the same body immersed in air because water weighs more than air.

The following experiment is to show that a floating body displaces enough of the liquid in which it floats to weigh just as much as the body:

EXPERIMENT 58.—Measure the outside diameter of the tube, figure 13, which is a cylinder. Divide this by 2 to find the radius. Square the radius. Multiply the square of the radius by 3.1416. You have now found the area of the circle which is the cross-section of the tube.

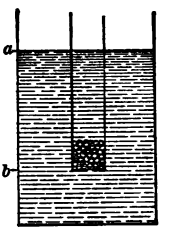

FIG. 13

Measure the depth to which the tube sinks in water. Suppose it sinks to the depth of 5 cm. According to the principles of fluid pressure, at any given depth the pressure is equal in all directions. Five centimeters of

water column would exert a pressure of 5 grams per square centimeter. Suppose the area of the bottom of the tube were found to be 4 square centimeters. Then the total upward pressure on the bottom of the tube would be 5 times 4 or 20 grams. This should be the weight of the tube. Weigh it. How does the result compare with the calculation?

In your experiment how many cubic centimeters of water did the tube displace? Float the tube in a graduate cylinder and see how many cubic centimeters of water it displaces.

A floating body displaces its own weight of the liquid (or gas) in which it is floating.

A canal boat displaces 1500 cubic feet of water. How much does the boat weigh?

1 cubic foot of water weighs about 62.5 lbs.

SPECIFIC GRAVITY.

EXPERIMENT 59.—To find the relative weight of two liquids by floating the same object in both liquids. Attach a pencil to a measuring stick with wire loops so that it may move freely, figure 14. Let the liquids for this experiment be water and concentrated salt solution. Nearly fill a glass cylinder with water. Float the pencil in it and note the depth to which it sinks. Remember that it must sink deep enough to displace its own weight of the liquid. Now float the pencil in salt solution. The salt solution is heavier than the water so the pencil will not sink so deep in it as in the water. Measure the depth to which it sinks in the salt solution. Suppose it sank 10.25 cm. deep in the water

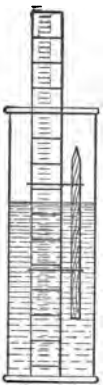

Fig. 14

and 10 cm. deep in the salt solution. A floating body displaces its own weight of the liquid in which it floats. Therefore a cylinder of fresh water 10.25 cm. long must weigh as much as the pencil, and a cylinder of salt water 10 cm. long must weigh as much as the pencil. So a cylinder of fresh water 10.25 cm. long weighs as much as a cylinder of salt water 10 cm. long. Calculate the relative weights of the two liquids. Find the ratio of the weights of equal volumes of the two liquids. This ratio is called Specific Gravity. Water is generally taken as the standard. Its specific gravity is, therefore, considered to be 1. What is the specific gravity of the salt solution in terms of water as the standard?

The above experiment suggests the use of the hydrometer, an instrument often made of glass weighted by a mercury bulb at one end, so as to float vertically when placed in a liquid. The instrument is used commercially for finding the relative weights of various liquids by measuring the depth to which it sinks in these liquids. In this manner the concentration of various liquids such as milk, alcohol, etc., may be determined.

Suppose a certain milk were to be tested. It would be necessary to know how deep the hydrometer would sink in milk of standard density. If the density of the milk were greater than the standard the hydrometer would not sink so deep and if the milk were not so concentrated as the standard the hydrometer would sink deeper in order to displace its own weight.

In a previous exercise we found that a floating body displaces its own weight of the liquid in which it floats.

A body that sinks displaces its own volume of the liqu in which it is submerged.

EXPERIMENT 60.—Use a large overflow apparatus made from a 32-oz. bottle or from a tin can. Fill the apparatus to the overflow. Weigh a heavy object—say a piece of lead or a stone—and then carefully lower it into the water. Collect in a graduate glass the water it displaces. Read the volume of water displaced. What must have been the volume of the object? Suppose the volume of the object were found to be 25 cubic centimeters and the weight 50 grams, 25 cc. of water would weigh 25 grams, but 25 cc. of this object weighs 50 grams; 1 cc. of this object, therefore, weighs 2 grams. Therefore this object is twice as heavy as water. This ratio of the weight of a given volume of an object to the weight of an equal volume of water is called the *specific gravity of the object.*

It is very convenient to be able to find the volume of an irregular body by immersing it in water and finding the volume of the water displaced. Instead of measuring in a graduate the volume of the water displaced another way to find it is to weigh the water displaced by the object and then assuming that the weight of 1 cc. of water is 1 gram, the volume may be readily calculated.

If it is necessary to perform the above experiment, using the English system of weight measure, the following method is suggested:

Weigh an object—a piece of granite for instance—in air. Then lower it into the overflow can. Collect the water displaced. Weigh the water displaced. One cubic inch of water weighs about four-tenths of an ounce. Calculate the number of cubic inches of water displaced. This is the volume of the object. Calculate from the weight and volume of the stone already found, the weight of 1 cubic inch of the stone. Compare the

weight of one cubic inch of the stone with the weight of 1 cubic inch of water. This quotient is the specific gravity of the stone.

The specific gravity of the above object may be more easily calculated by dividing the weight of the stone by the weight of the displaced water. This will give us directly the ratio of the weights of equal volumes of stone and water.

EXPERIMENT 61.—Another method of finding the specific gravity of a body that will sink in water is as follows:

Weigh the object in air.

Weigh the object suspended in water.

Find the difference. This difference is the buoyancy of the water on the object. It is the weight of the water which the object displaces. It is the weight of a volume of water equal to the volume of the object.

Compare the weight of the stone with the weight of an equal volume of water. This ratio will be the specific gravity of the stone.

EXPERIMENT 62.—Experiment to find the specific gravity of a liquid by means of the method of the specific gravity bottle:

Weigh a bottle empty.

Weigh the bottle filled with water.

Subtract to find the weight of the water.

Weigh the bottle filled with salt solution or other convenient liquid.

Subtract the weight of the bottle from the above weight to find the weight of the salt solution.

Divide the weight of the salt solution by the weight of the water to find how many times as heavy as the water the salt solution is. This quotient will be the specific gravity of the salt solution.

Mechanics of Gases.

WEIGHT OF AIR: BUOYANCY.

EXPERIMENT 63.—To show that the air has weight:

A hornpan balance may be used for this experiment. The balance should be sensitive to the hundredth of a gram. An eight-ounce flask is provided with a rubber stopper containing one hole. By means of a piece of glass tubing in the hole of the stopper, a small piece of rubber tubing containing a glass plug is attached. The whole is carefully balanced. The plug is then removed and by means of the lungs some air is drawn out of the flask. The rubber tube is tightly pinched while the plug is reinserted. The scale pan carrying the flask shows a decrease in weight. The above process is repeated until the pan carrying the flask is very decidedly lighter. Weights are now added to restore the balance. The weight added represents the weight of the air which was exhausted from the flask. This, of course, is only a small decimal part of a gram. To find what volume of air has been exhausted from the flask, the flask is removed from the scale pan and inverted over a basin of water. When the plug is removed from the rubber tube the water from the basin runs up into the flask to take the place of the air which has been drawn out. This water is carefully measured in a graduate cylinder. By this means the number of cubic centimeters of air which was exhausted is obtained. We now have data for calculating the weight of a liter (1000 cubic centimeters) of air.

A liter of air weighs about 1.29 grams.

How does the calculated result compare with the standard?

A liter of water weighs 1000 grams.

Compare the weight of water with the weight of air.

A cubic foot of water weighs 62.5 lbs.

About how much does a cubic foot of air weigh?

EXPERIMENT 64.—To show that ether vapor has weight and can be poured from one vessel to another:

Is ether vapor heavier or lighter than air?

Put a few drops of ether in a wide-mouthed bottle and allow it to stand until they have evaporated. Hold this bottle as though you would pour something from it into a second similar bottle. The second bottle may now be shown to contain the ether vapor by bringing a lighted match to it.

Since air has weight it exerts pressure. The pressure of the air increases with, but is not proportional to the depth. At any given depth the pressure is equal in all directions.

Archimedes' Principle applies to gases as well as to liquids: *A body submerged in a fluid is buoyed up with a force equal to the weight of the fluid displaced by it.*

A cubic foot of air weighs about 1.28 ounces at the sea level. If a balloon displaces 3000 cubic feet of air how many pounds of buoyant force would it have at the sea level? What would be the buoyant force at a height of 3 miles where the air weighs half as much?

Explain why an object would weigh more in a vacuum than in the air.

EXPERIMENT 65.—We may cause a fountain to play by means of atmospheric pressure. Take a 12-ounce bottle with a narrow neck carrying a No. 1 rubber stopper with one hole, figure 15. Through the hole run a 6-inch piece of glass tubing with one end constricted so that it will throw a jet. The constricted end goes up into the bottle. To the other end attach a short piece

of rubber tubing. Using the rubber tube for a mouth piece, exhaust some air from the bottle by means of the lungs. Then invert the bottle and allow the rubber tube to dip into water. The pressure of the atmosphere forces considerable water into the bottle to take the place of the air exhausted.

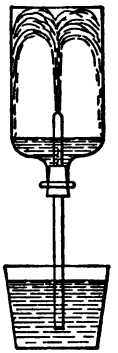

Fig. 15

EXPERIMENT 66.—Use the same piece of apparatus to show a fountain by compressed air. Turn the glass tube around so that the constricted end shall be out of the bottle. Use the rubber tube for a mouthpiece and allow the glass tube to dip into water in the bottle. The bottle should be about half full of water. Close your mouth over the tube and compress air in the bottle. Then draw off the rubber tube and a fountain will play from the bottle into the air. The pressure of the air inside the bottle is greater than the pressure of the air outside of the bottle.

EXPERIMENT 67.—Use a 32-ounce wide-mouthed bottle carrying a solid rubber stopper. Vaseline the stopper so that the large end of an Argand chimney may rest on it "air tight." Into the smaller end of the chimney fit a rubber stopper with one hole, through which insert a piece of glass tubing connected with a small piece of rubber tubing. By means of the lungs exhaust air from the chimney and you will be able to lift the bottle from the table.

This experiment illustrates the principle on which the Magdeburg Hemispheres work.

COMPRESSIBILITY OF AIR: BOYLE'S LAW.

EXPERIMENT 68.—Take a long glass tube three-

sixteenths of an inch in diameter, placing the finger tightly over the top, attempt to lower the tube into a jar of water. The water cannot rise to fill the tube because the tube is already filled with air. If the jar of water is very deep it will be noticed that the air in the tube is compressed into less and less space as the tube is lowered deeper and deeper into the water. If the tube could be lowered to a depth of 34 feet, that is, to such a depth that the difference between the level of the water in the tube and the level of the water in the jar was 34 feet, the volume of the air in the tube would be only one-half what it was when the tube was just below the surface of the water. Because 34 feet of water represents a pressure of one atmosphere, and at a depth of 34 feet of water the air in the tube would be under the pressure of the atmosphere +34 feet of water, or under the pressure of two atmospheres. According to Boyle's Law (the volume of a gas varies inversely as the pressure it supports) the volume of the air would be one-half what it originally was.

If the finger is removed from the top of the glass tube while the lower end is considerably below the surface of the water in the jar, the water will rise in the tube to the same level as it stands in the jar or a trifle higher, because of capillarity. As the tube is raised gradually out of the cylinder of water the water will continue to stand at the same level inside the tube as in the cylinder. The water in the tube and in the cylindrical jar are both now under the same pressure,—the pressure of the atmosphere.

As bubbles of air set free under the surface of a liquid rise to its surface, they become larger because

as they rise to the surface they are under less and less pressure, until finally they are under the pressure of simply the atmosphere.

How deep in water would a bubble have to be liberated in order that when it reached the surface it would have twice as great a volume as when set free? Thirty-four feet of water represents the same pressure as the atmosphere, so if the bubble were liberated at a depth of 34 feet it would then be under two atmospheres of pressure. When it reached the surface, therefore, it would be under only one-half the pressure it was under when liberated. Its volume would therefore be twice what it originally was.

EXPERIMENT 69.—Bend a glass tube about a foot long into the form of a J so that the short end is about 4 inches long and the long end 6 inches. Close the short end. Put mercury into the tube and adjust the mercury so that it stands at the same level in both arms. Now add mercury to the long arm. The volume of air in the short arm becomes decreased as the pressure on it (due to the weight of the mercury) is increased. All gases are equally reduced in volume when subjected to the same pressure, and the law which relates to the relation between volume and pressure is called Boyle's Law, and is stated as follows: *The volume of a gas varies inversely as the pressure it supports.* That is, if a gas occupies a certain volume at a pressure of say 15 pounds per square inch, its volume will decrease to one-half what it originally was if the pressure becomes 30 pounds per square inch; one-third what it originally was if the pressure becomes 45 pounds; three times what it originally was if the pressure becomes one-third, or 5

pounds. These results may be tabulated as follows:

VOLUME—1 cc.: PRESSURE—15 lbs. per sq. in.

VOLUME—One-half cc.: PRESSURE—30 lbs.

VOLUME—One-third cc.: PRESSURE—45 lbs.

VOLUME—3 cc.: PRESSURE—5 lbs.

Should it be found desirable to obtain such results as these at first hand, the conventional Boyle's Law apparatus may be employed. The apparatus consists of a long J-shaped tube closed at the short end, and mounted on a board carrying a scale. A small quantity of mercury is added and adjusted so as to stand on a level in both arms. The enclosed air is then at the pressure of an atmosphere. The barometer must be read in order to ascertain the pressure of the atmosphere. It is usually about equal to 30 inches, or 76 centimeters of mercury. Suppose it reads 76 centimeters. Next read the height of the enclosed air space. Say it is 10 centimeters. Record as follows:

VOLUME—10 centimeters: PRESSURE—76 centimeters.

Now increase the pressure by adding mercury. The pressure is now 76 centimeters, plus the number of centimeters added. Read the volume of air and record again:

VOLUME:..... PRESSURE: 76 centimeters +.....

Continue to add mercury several times and read and record as above.

See if the product of the pressure by the volume is always constant. Does the volume of the air vary inversely as the pressure upon it?

THE BAROMETER.

EXPERIMENT 70.—We filled with mercury a stout glass tube, about 33 inches long and one-quarter inch

interior diameter, sealed at one end. We tightly closed the open end of the tube with the finger and inverted it, placing the end of the tube in a dish of mercury. The mercury in the tube stood about 30 inches above the surface of the mercury in the dish. The pressure of the atmosphere was sufficient to maintain a column of mercury 30 inches high. This was as long a column of mercury as the atmosphere could sustain at the sea level. If we had tried the experiment on top of a high mountain the mercury column would not have stood so high, because there would not have been so much air over the mercury to press on it.

The height of mercury column which the atmosphere will hold up varies slightly from day to day. That is, the pressure of the atmosphere varies from day to day. The normal pressure is sufficient to hold up a mercury column 30 inches high. This represents a pressure of 15 pounds per square inch. Why?

If water were used instead of mercury the column would have to be at least 13.6 times 30 inches long. Why?

The barometer measures the pressure of the atmosphere but not the height of the atmosphere. It cannot measure the height of the atmosphere because air is compressible.

Pressure in gases increases with the depth, but is not proportional to the depth.

Pressure in liquids is proportional to the depth.

THE SIPHON.

EXPERIMENT 71.—The apparatus illustrated in the following experiments is called the Siphon.

It is a tube with *unequal arms*, for conveying liquids

from one vessel over an elevation to another vessel at a lower level by means of *atmospheric pressure.* (Figure 16.)

To start the siphon working, fill the tube with water, then close each end with a finger. Place the end of the shorter arm in the liquid to be transferred. (This may be a tumbler of water placed on a retort stand considerably above the level of the table.) Bring the end of the longer arm to a lower level, and open the ends. Place under the longer end a tumbler to receive the water that is transferred from the higher vessel. The flow will continue until the liquids stand at the same level or until air enters the tube at the end of the shorter arm.

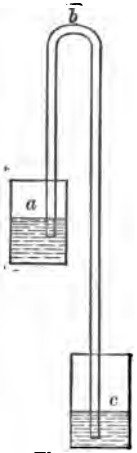

Fig. 16

To explain the working of the siphon we need to consider pressure in both liquid and gas. Suppose, in figure 16, the distance *ab* is 15 inches, and *bc* is 30 inches, and the liquid is mercury. Atmospheric pressure at *c* is balanced by the weight of the column of mercury *bc*, but the column of mercury *ab* exerts only half an atmospheric pressure. Hence the atmosphere is capable of lifting the column *ab* and pushing it against the column *bc* with a force of 7½ pounds per square inch. This is the force which operates the siphon.

Could a siphon work without atmospheric pressure?

Consider the behavior of a siphon if the pressure of the atmosphere were removed.

Examine the "Tantalus Cup," which is an interesting form of the siphon.

Examine and explain other forms of the siphon.

PUMPS.

EXPERIMENT 72.—Tie a piece of rubber cloth over the large end of a lamp chimney, figure 17. In the other end put a rubber stopper having two holes. Insert glass tubes as indicated in the figure. Make a valve for the hole *b* out of rubber cloth. Use your finger for a valve at *a*. Close the finger of one hand over *a*. Seize the rubber cloth with the other hand and lift. Your lifting balances in a measure the pressure of the air down upon the rubber cloth and the pressure of the air at *c* forces water up through *b* into the chimney. Now remove the finger and push down on the rubber cloth. The valve *b* closes and the water passes out of the chimney through *a*.

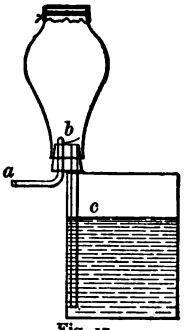

Fig. 17

As a substitute for the finger a valve may be made of a short piece of rubber tubing drawn over the end *a*. Plug the end of this rubber tubing and cut a short slit in its side. (This is fully described in Vol. I, p. 93.)

Or the tube *a* may be removed altogether and a valve similar to *b* put over the hole on the under side of the stopper.

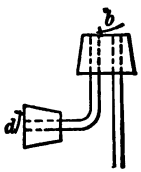

Fig. 18

Or put a rubber stopper having one hole over the lower end of the tube *a*. Over this hole put a valve of rubber cloth *d*. Figure 18 illustrates it. The rubber stopper carrying the valve *b* is the one which fits into the lower end of the lamp chimney in figure 17.

EXPERIMENT 73.—To show the effect of an air chamber upon the action of a pump, attach to the apparatus of figure 17 the piece of apparatus represented in figure 19. Connect *f*, figure 19, with *a* figure 17, by a short piece of rubber tubing. Over the lower end of the tube *f*, a valve, *d*, is placed. The upper end of the tube *e* is nearly closed, leaving a pin-hole. By the working of the lamp-chimney pump water is forced through *d*. The air in this bottle is somewhat compressed thereby and keeps a continuous stream flowing from *e*.

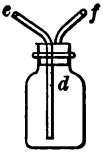

Fig. 19

Of course any pump that will pump water must of necessity be able to pump air.

EXPERIMENT 74.—Attach the apparatus of figure 19 to that of figure 17 and show that carbon dioxide gas (Vol. 1, p. 17.) may be pumped from *c* to *d*. Test its presence in the second bottle by lime water.

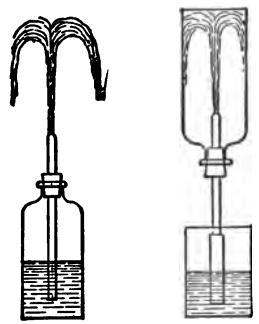
Fig. 20

Show also that ether vapor may be pumped from *c* to *d*. Test its presence in the second bottle by a lighted match.

EXPERIMENT 75.—Examine a bicycle pump as a means of condensing air. What adjustment is necessary to convert it into an exhausting pump. Secure such a combination pump for condensing and exhausting experiments, such as are illustrated by figure 20.

EXPERIMENT 76.—To illustrate miscellaneous principles in the mechanics of fluids. Fill a small vial

partly with water and partly with air so that it will barely float in water, *a*, figure 21. Adjust another so that it will barely sink in water, *b*, figure 21. Place these in a large bottle of water and tie rubber cloth air-tight over the mouth.

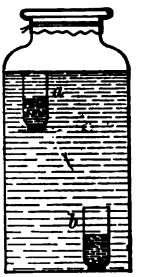

Fig. 21

Press down upon the rubber cloth. Notice that the water line in *a* rises and the small vial sinks to the bottom of the large bottle. The pressure which you exerted upon the rubber cloth was *transmitted* through the air and through the water in the large bottle. It *acted equally in all directions.* It *compressed* the air in the small vial and forced more water into it. The vial *a* then *displaced less than its own weight of water* and sank.

Remove your pressure from the rubber cloth. The water line in *a* sinks to its original level and the small vial again rises to the top of the water in the large bottle. The air in the vial is *perfectly elastic* and *whenever pressure is removed regains its original volume. Its volume varies inversely as the pressure upon it. The weight of water finally displaced by the glass and the air in the vial equaled the weight of the vial. This weight of water pressing down to get into the lowest position balanced the weight of the vial* and buoyed it up.

Seize the rubber cloth and pull upward. Notice that the water line in the vial *b* sinks and the vial rises to the surface of the water in the large bottle.

The atmospheric pressure of about 15 lbs. per square inch was exerted through the rubber cloth upon the air in the large bottle and through the air in the large bottle upon the water and through the water in all directions,

determining the volume of the air in the vial *b*. When the rubber cloth was pulled upwards the pressure of the air down upon it was in a measure balanced, and the air in the vial under the reduced pressure expanded accordingly, driving out some of the water. When the weight of all the water displaced by the glass and the air inclosed within it was greater than the weight of the vial, the vial was buoyed up to the surface of the water in the large bottle. Changes in the pressure of the atmosphere are indicated by the positions of the vials. In an area of high barometer both vials are down and in an area of low barometer both vials are up.

HEAT.

SOURCES.

EXPERIMENT 77.—To illustrate the production of heat by chemical action, repeat here experiment 6. When the sulphuric acid is poured upon the sugar solution, the sugar behaves as though it were being heated on the stove and finally becomes a charred mass, figure 22.

Fig. 22.

EXPERIMENT 78.—Bring together on a plate a small piece of phosphorus and a few scales of iodine. The chemical action is vigorous and the heat produced thereby causes a flame which sends up beautiful violet vapors.

Caution.—Cut phosphorus under water and always handle it with forceps.

EXPERIMENT 79.—On a good-sized chunk of quicklime pour about twice its volume of water. The chemical action soon raises the water to the boiling point.

In the above experiment a chemical change has taken place. The lime or calcium oxide has combined with the water and a new compound, calcium hydroxide, has been produced. The "quick" lime has now become "slaked" lime. In this form it is used for building purposes. (After the addition of a little sand, it is called "mortar," or with sand and hair it forms "plaster.")

This experiment is often met in every-day life. When large quantities of quick-lime are used a very great amount of heat is evolved by the chemical combination of the lime with the water.

Flames usually attend the production of heat by chemical action. All flames are gas flames. In the case of an illuminating gas flame the gas is burned directly. In case of a kerosene lamp flame it is the vapor of kerosene that is burning. In the case of a candle the wax first melts and is then converted into a vapor which burns.

A flame, then, is a burning gas.

A flame in the ordinary sense is the union of a gas with the oxygen of the air.

EXPERIMENT 80.—The Bunsen burner flame is the union of a gas with oxygen.

First study the construction of the burner itself. Open it by unscrewing its various parts. Notice the small constricted opening through which the gas is admitted. We may constrict this more or less. If we open it wider more gas can get through. If we pinch it, less gas will be admitted. Notice the "chimney" withholes in the base for the admission of air and the "collar" which also contains holes.

Put the burner together again and close the holes in the "chimney" and "collar." Light the gas. Notice that the flame is bright yellow and very luminous. Hold a cold dish in the yellow flame and notice the particles of "lamp-black" that are deposited on it. These are particles of carbon. The luminosity of the flame is probably due to the fact that these particles of carbon are heated intensely hot so that they glow. The carbon

comes from the decomposition of the gas; the gas is composed chiefly of carbon and hydrogen.

Now open the holes so as to admit the air. Notice that the flame is no longer luminous, but almost colorless. This "blue" flame is very much hotter than the yellow flame. The combustion in this case is more perfect because more oxygen has been supplied to the gas. The particles of carbon that glowed before are now being burned up and are passing off in the compound carbon dioxide.

Now notice the structure of the flame. If the burner is in good condition there will be a very distinct blue cone surrounded by an almost colorless envelope of flame. Combustion is not taking place in this blue cone. It contains unburned gas. This can be proved in several ways:

(1) Put one end of a small glass tube into the blue cone and tip the other end of the tube up. Bring a flame to the raised end. A flame will persist at this end of the tube.

(2) Hold a sliver of wood horizontally in the flame. The sliver will be burned only where it comes in contact with the burning envelope which surrounds the blue cone.

(3) Thrust the tipped end of a match into the blue cone. It does not take fire.

(4) Notice the ring which is burned on a piece of glazed paper by bringing it down on top of a Bunsen burner flame.

EXPERIMENT 81.—Collect over water, an eight-ounce bottle of illuminating gas. Light it by bringing a burning taper to its mouth. Notice that the gas burns only at the mouth of the bottle where it is coming in contact

with oxygen. Hold the bottle mouth downward and insert the burning candle up into the bottle. Notice that it is extinguished. The candle cannot burn in an atmosphere of illuminating gas. Why?

Now fill several eight-ounce bottles with water. Introduce varying amounts of illuminating gas, say one-eighth, one-quarter, one-half, three-fourths. Allow air to enter the bottles to mix with the gas and let them stand for a few seconds. Now bring a candle flame to the mouth of each bottle. In some cases the gas will burn more or less quietly for a short time. In other cases there will be quite a sudden burning throughout the whole mass at once. This latter is an "explosion." If the flash takes place instantaneously the gas and air were mixed in just the right proportions for a perfect explosive mixture. An explosion, then, is a burning throughout the whole mass at one time, or in other words very rapid combustion throughout the whole mass at once. If the explosion is confined in a small space a loud noise and more or less damage may result, but neither of these effects are noticed when the explosion takes place in a wide-mouthed bottle.

Which proportion of gas to air made the best explosion? This is perfect combustion, and the Bunsen burner attains as near to that proportion as possible without quite reaching the explosive mixture. When that is reached the flame "strikes back."

EXPERIMENT 82.—To illustrate the production of heat by friction. Rub the tipped end of a friction match on a rough surface like ground glass. Heat enough is produced by friction to start the chemical action, which in its turn produces heat. It is difficult to light the match upon the smooth side of the glass. Why?

EXPERIMENT 83.—Drive a good-sized nail nearly to its head into a block of sound spruce and immediately draw it out with a claw hammer. The heat developed by friction and percussion will make the nail too hot to hold in the hand.

EXPERIMENT 84.—Rub the hands together violently. Test the heat produced by laying them upon your cheeks.

Notice the sparks produced by the striking of a horse's shoe against the pavement. This is what occurs when a piece of steel is struck a glancing blow with a flint. Consider the action of flint-lock guns; the heating of a saw in cutting wood; the heating of wagon and car axles when friction is not reduced by much oil; the heating of the hands by sliding over a rope.

Heat is produced also by compression. A bicycle pump often gets very hot when used to pump air into a tire. This heat is due partly to friction and partly to compression. The air is being compressed into the tire, and this crowding of the particles of air closer together results in the production of heat.

EXPERIMENT 85.—Fit an eight-ounce flask with a number 3 stopper containing two holes. Through one hole insert a thermometer. Through the other run a right angle bend. Attach to the latter a short piece of rubber tubing. Fill the flask about one-third full of water, and adjust the thermometer so that its bulb is just above the surface of the water in the flask. Now heat the water gradually, shaking the flask all the time to keep it thoroughly moistened. Note the temperature when the water boils. The boiling point has been reached when the thermometer reading

remains constant. A Fahrenheit thermometer will register about 212°, and a Centigrade thermometer will register about 100° when the water is boiling. No matter how long the water is heated its temperature will not rise above the boiling point if the steam is allowed to freely escape. But if the rubber tube is now pinched so that the steam cannot escape, the pressure inside of the flask will be increased and the thermometer will rise above 212° or above 100°. The water is now boiling under increased pressure, and its boiling point is consequently higher. Do not allow the thermometer to rise more than two or three degrees above the normal boiling point. This method of raising the boiling point by increasing the pressure is resorted to in cases when it is necessary to have a higher temperature than the normal boiling point, to cook certain foods. Gelatine is extracted from bones by this means, in an apparatus called a Papin Digester.

The modern conception of heat is that it is molecular motion. That is, that it is a vibration of the particles of matter. Whatever increases these vibrations makes the body hotter. When the body is cool its particles are not in such rapid vibration. All bodies have more or less heat because their particles are all in motion. The absence of molecular motion would mean the absence of heat or absolute cold. This state of affairs is utterly outside our experience.

Recall all the experiments in the production of heat above mentioned. Explain them in the light of the theory of heat. Instead of reading "how heat is produced," the heading might be "how molecular motion is produced."

Whenever resistance is offered to an electric current,

heat is produced. A large wire offers less resistance than a small wire of the same material, because its cross-section is greater and the current may therefore flow through it more easily. If one wire has twice as great a diameter as another, its area is four times as great and consequently it is four times as easy for the current to pass through, and we say that the resistance of the large wire is only one-quarter as great as that of the small wire. The resistance offered by wires is dependent not alone upon their size. It is dependent also on the material of which they are made. A piece of german silver wire will offer a greater resistance than a piece of copper wire of the same size. It follows, then, that a piece of very small german silver wire will offer a comparatively great resistance,—resistance enough to produce heat.

EXPERIMENT 86.—Connect two or three dry battery cells in series; that is, the carbon pole of one joined to the zinc pole of the other. Send the current through a piece of small german silver wire (No. 30). The wire will become too hot to touch. Touch it to a piece of paraffin. It will melt its way into the paraffin. Wrap the wire around a thermometer bulb. Note the rise in temperature.

The filament in an incandescent electric light bulb becomes red hot because it offers great resistance to the electric current which is being sent through it.

Our electric cars are warmed by coils of wire which become hot because they offer resistance to the passing of the current.

Electric ovens for purposes of cooking are really resistance boxes. So are electric irons.

EFFECTS OF HEAT.

EXPERIMENT 87.—Through the hole of a No. 1 rubber stopper, fit a piece of glass tubing about a foot in length. Insert the stopper carrying the tube into a two-ounce flask completely filled with water. Wipe the flask dry and heat very gently over the Bunsen burner flame. Notice that the water expands very perceptibly, rising in the tube and even overflowing it.

EXPERIMENT 88.—Rub the palms of your hands together briskly, and when the hands are quite warm hold them on the bulb of the air thermometer (figure 23). The bulb of this thermometer is the two-ounce flask which is connected with the bottle of colored liquid by means of a long glass tube. Notice that the flask contains a rubber stopper and the lower vessel contains an ordinary cork. When the hands are placed on the flask containing air there is evidence that the air is expanding, because the liquid is driven down in the tube and the air bubbles out through the liquid. Remove the hands and notice that as the flask cools the liquid rises. This is a thermometer in which the liquid falls when the temperature rises, and rises when the temperature falls. The bulb of the thermometer is at the top.

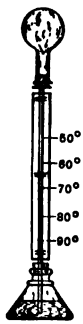

Fig. 23.

An air thermometer is very sensitive because air expands very much for a small rise in temperature.

All gases expand alike for a given rise in temperature, but each liquid and each solid has its own individual rate of expansion.

EXPERIMENT 89.—Fill three vessels with water. Into the first (*a*) put water at about the temperature of the

room; into the second (*b*) put ice water, and into the third (*c*) put water containing ice and salt. For a few seconds hold the fingers of one hand in *a* and of the other hand in *c*. Then put both hands into *b*. *b* feels warm to the hand that has been in *c* and decidedly cool to the hand that has been in *a*. Evidently our senses are not reliable for measuring temperatures. We can only tell whether a body is relatively hot or cold. A body feels cold if it is taking heat from our hand and warm if it is giving heat to the hand. Even ice water feels warm to a finger that has been plunged into a freezing mixture of ice and salt, but it feels cold to a finger that has been in water at the temperature of the room. To reliably measure the temperature of bodies an instrument called the thermometer is used. The thermometer in most common use consists of a glass tube containing a threadlike bore blown into a bulb at one end. The bulb is filled with mercury. The thermometer is based on the principle that heat expands liquids. The mercury is expanded by heat so that it has to occupy more space and in so doing it crawls up into the threadlike tube which is marked off in divisions called degrees. The graduation is accomplished as follows: The bulb of the thermometer is surrounded by the steam from boiling water and the height of the mercury column is marked on the glass. This is the boiling point of water. On a Fahrenheit thermometer this point is marked 212°. On the Centigrade thermometer it is marked 100°. Next the thermometer bulb is plunged into cracked ice. The mercury of course contracts and the upper end of the column sinks. When this remains constant the point is marked and this is called the freezing point. On the Fahrenheit

scale this point is marked 32° and on the Centigrade 0°. Equal divisions are next made between the freezing and boiling point and these are marked off on the stem. It will be noticed that the difference between the boiling and freezing point on the Fahrenheit scale is 180° and on the Centigrade scale 100°. The marking of the boiling and freezing points is purely arbitrary.

To test a thermometer:

EXPERIMENT 90.—Notice whether the thermometer you decide to test is marked in Fahrenheit or Centigrade scale. Take an 8-ounce flask (one-third full of water) carrying a rubber stopper with two holes. Through one hole insert a thermometer, and through the other a right-angle bend. Have the thermometer bulb come just above the surface of the water in the flask. Heat the water to the boiling point. Notice that the thermometer continues to rise until it reaches a point where it remains constant. This is the boiling point. See if there is any error in your thermometer. Now test for the freezing point by imbedding the thermometer bulb in cracked ice. Have the ice in a funnel so that as the ice melts the water may run out, leaving the ice as dry as possible. Does the thermometer register correctly?

By expansion heat changes the states of matter. Consider the melting of ice, paraffin, etc., and the vaporizing of water, ether, etc., by heat.

It is important to know that substances cannot change from solid to liquid or from liquid to gas without absorbing a definite amount of heat. Snow and ice in a temperature above the melting point remain so long in the solid state only because they cannot get rapidly the heat necessary to change their state. This is true of ether

and other volatile liquids and conspicuously so of liquid air, which may be kept for a surprisingly long time in an open vessel. It is incapable of getting the required amount of heat for its change of state.

This discussion carries us into a study of methods of transferring a state of heat (or molecular motion) from one substance to another. It will not be clear until we take up the study of *latent heat.*

CONDUCTION.

EXPERIMENT 91.—Hold in the flame an iron and a copper wire fastened together at one end. Hold the free ends, one in each hand. Notice that the two wires do not conduct equally well. Which is the better conductor? When we speak of good and poor conductors we mean relatively good and poor. Generally speaking the metals are good conductors.

Why do some things feel cold to the touch while others in the same atmosphere feel warm? Because some things are much better conductors than others and conduct the heat from the body faster than others. The metals generally feel cold to the touch. Things which are good conductors do not retain their heat so long as things which are poor conductors. Bad conductors, therefore, may be used to impede the flow of heat into or out of bodies; that is, they may be used to keep hot bodies hot and cool bodies cool. Try the conductivity of wood and glass.

Why does wrapping a piece of ice in flannel or felt keep it cool while wrapping the body in the same material makes it warm?

EXPERIMENT 92.—Bring wire gauze with very fine mesh over a flame. The wire conducts away the heat

so fast as to stop the combustion. This is made use of in the Miner's Safety Lamp.

EXPERIMENT 93.—Wrap wire gauze into a cylinder, placing corks in either end and a lighted taper inside to represent a Miner's Safety Lamp. Figure 24. Fill a 32-oz. wide-mouthed bottle with the best explosive mixture of gas and air (experiment 81). This represents a coal mine ready to explode. Introduce a Miner's Safety Lamp. There is a slight explosion inside the gauze (which would warn the miners to leave), but when the flame starts to pass through the gauze its heat is conducted away so fast that its combustion ceases at that point.

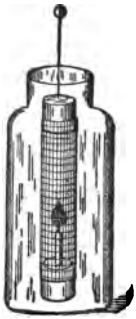

Fig. 24.

The gas in a mine is often called by the miners "fire-damp." It is a compound of carbon and hydrogen. When it burns water vapor and carbon dioxide are produced. The latter is called by the miners "choke-damp."

If a flame (protected or unprotected) is lowered into a mine in which an explosion has already occurred it goes out because it cannot burn in carbon dioxide. Old wells are sometimes tested for carbon dioxide in this way.

CONVECTION.

EXPERIMENT 94.—To illustrate how water may be heated in a hot water tank, prepare the apparatus represented in figure 25 and apply the flame. At first the two columns of water balance each other, but when the column *B* is

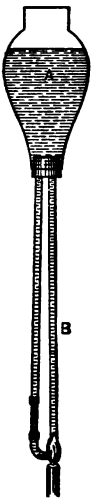

FIG. 25

heated it expands and some of the water in it is pushed out. It therefore becomes lighter than the other column which now pushes down underneath it and drives it on up into the chimney, whence colder water is continually supplied to push on the water heated by the flame.

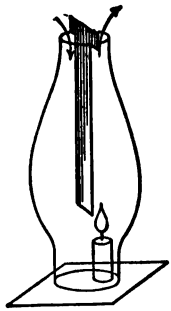

Fig. 26.

In a similar manner air currents are produced as is shown in figure 26—heating and ventilating systems.

RADIATION.

EXPERIMENT 95.—Consider how heat gets from an incandescent electric light bulb. There is no air between the filament and the glass walls of the bulb. Hence neither conduction nor convection can avail. Cover one-half of the bulb with tin-foil and hold one hand about half an inch from the tin foil and the other hand half an inch from the glass side. The tin-foil not only cuts off the visible radiation (light) but also most of the invisible radiation (heat).

EVAPORATION—LATENT HEAT.—SOLUTION.

EXPERIMENT 96.—Put the bulb of a thermometer into a bottle of ether. Its temperature is not far from that of the room. Now take a little of the ether out into a shallow dish and fan it to facilitate its evaporation. The thermometer will show that its temperature has fallen as low or lower than the freezing point of water. Indeed a drop of water may be turned to ice in the ether. In order to change its state from liquid to gas

the ether *must* take heat from something and cause it to disappear. It is a physical impossibility for the ether or any liquid to change to a gas without absorbing heat—and a definite amount of heat—and rendering it *latent.* We say *latent* because that definite amount of heat appears again when the ether changes back again from gas to liquid.

When any body passes to a liquid state from a solid state, or when any body passes from a liquid state to a gaseous state, heat disappears.

EXPERIMENT 97.—Set a vessel of water to heat over a Bunsen burner. The temperature of the water gradually rises until it reaches the boiling point of the water (100° Centigrade). After this, no matter how long the heat is applied, the temperature no longer rises. What becomes of the heat which is being supplied to the water if it is not being used to effect temperature changes? It is being used to convert the liquid water at 100° into gaseous water (steam) at 100°. In other words it becomes latent. It takes as much heat to convert 1 gram of water at 100° into 1 gram of steam at 100° as to raise 537 grams of water one degree Centigrade. It takes 537 calories of heat to convert 1 gram of water at 100° into 1 gram of steam at 100°. (A calorie of heat is the amount of heat it takes to raise 1 gram of water from 0° c. to 1° c.) It is customary to say that the latent heat of the vaporization of water is 537. It takes large quantities of heat, then, to change the state of a substance from liquid to vapor, or from solid to liquid. It takes 80 calories of heat to change 1 gram of ice to water.

If heat disappears when bodies change from a more solid to a less solid state, we should expect the temperature to fall when solids like salt, for instance, are dis-

solved in water. It takes heat to dissolve the salt in the water. This heat is taken out of the water in which the salt is dissolving and therefore the temperature of the solution must fall.

EXPERIMENT 98.—Take the temperature of some water in a beaker. Add as much salt as the water will dissolve, stirring constantly. Note the change of temperature. This temperature change is much more striking in the case of some other less common salts that dissolve in water. Take ammonium chloride (sal ammoniac) for instance. Repeat the above experiment, substituting ammonium chloride for the sodium chloride (common salt).

Repeat the experiment using ammonium nitrate.

The following experiment illustrates the temperature changes in a much more striking manner.

EXPERIMENT 99.—Weigh out 50 grams of ammonium chloride and 100 grams of ammonium nitrate. Mix these two well together. Measure out into a vessel 150 cc. of water. Pour the mixture of the two salts into the water and while they are dissolving stir with a test-tube containing a thimbleful of water. The temperature of the solution will fall so low that the water in the test-tube will be frozen.—Freezing mixtures. Heat becomes latent when bodies pass from the liquid to the gaseous state as well as when they pass from the solid to the liquid state. Liquid sulphur dioxide evaporates so rapidly when poured upon water that it takes heat enough from the water to reduce it to the freezing point. See experiment 9.

Put a drop of ether, alcohol or benzine on the finger. In evaporating these volatile substances take heat enough from the finger to cool it very perceptibly.

We have already noted that when bodies pass from a solid to a liquid state heat disappears or becomes latent.

When bodies pass from a liquid to a solid state the heat which became latent reappears. For instance, it takes heat to change water at 100° to steam at 100° but when steam at 100° changes back to water at 100° that heat reappears.

EXPERIMENT 100.—To find how much heat reappears when a gram of steam condenses to a gram of water:

We take for our unit of heat the calorie (the amount of heat it takes to raise 1 gram of water 1° C.). The experiment, then, is to find how many calories of heat are given off by the condensation of 1 gram of steam.

Weigh out in flask *a*, figure 27, 200 grams of water. (The stopper in this flask must have a second hole to permit of expansion.) Heat the water in the flask *b* to the boiling point. Record the original temperature of the water in *a* and allow the delivery tube to dip into the water. The steam will be heard condensing in the cold water. Allow this to continue until the temperature has risen to somewhere near 70°. Then remove the delivery tube. Stir the water well and read the temperature. (Call this the resulting temperature). Then weigh again. The increase over the 200 grams will be due to the addition of the steam which condensed to water at 100° and then fell to the resulting temperature. Suppose the resulting temperature was 70°. Then the con-

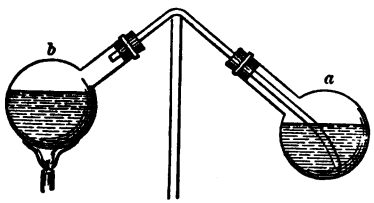

Fig. 27.

densed steam or water at 100° fell through 30°. What was the original temperature in your experiment? What was the resulting temperature? Through how many degrees was the 200 grams of water raised? How many calories of heat must have been added to the water? These did not all come from the liquefying of the steam because some heat came from the condensed steam falling from 100° to the resulting temperature. We will assume a case in order to work out the results:

Weight of water 200 grams. Original temperature 20°.

Resulting temperature 75°. Steam added 20 grams.

Condensed steam fell (100°—75°) 25°.

Water rose (75°—20°) 55°.

Number of heat units added=200 times 55=11,000.

Number of heat units that came from condensed steam at 100° cooling to 75°=20 times 25=500.

Number of heat units that came from the liquefying of 20 grams of steam=11,000—500=10,500.

Number of heat units from the liquefying of 1 gram of steam=10,500 divided by 20, or 525.

The standard result for the latent heat of the vaporization of water is 537.